Data Center Power Requirements:
Measurements From Silicon Valley

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Abstract

Current estimates of data center power requirements are greatly overstated because they are based on criteria that incorporate oversized, redundant systems, and several safety factors. Furthermore, most estimates assume that data centers are filled to capacity. For the most part, these numbers are unsubstantiated. Although there are many *estimates* of the amount of electricity consumed by data centers, until this study, there were no publicly available *measurements* of power use. This paper examines some of the reasons why power requirements at data centers are overstated and adds actual measurements and the analysis of real-world data to the debate over how much energy these facilities use.

1. Introduction

Current reports of data center energy use are mostly exaggerations. There are numerous accounts of data centers that consume over 1000 W/m^2 of power—more than ten times what is required by a typical commercial office space—as well as accounts of facilities that require a large fraction of the power put out by a single power plant.[1] For example, prospective builders of a data center in Sacramento, California told the local utility that they would need 50 to 60 MW of power,

roughly the equivalent of all other growth in the area in an average year [1]; and a single data center in New Jersey requested an amount of power equal to one-third of that used by the entire city of Newark [2]. Overstated energy demands such as these are problematic. For data center owners, overstated demands lead to extra construction expenses and less energy efficient facilities; for utility planners, these assertions lead to the building of excess generation, transmission, and distribution capacity; and for the public they perpetuate the urban legend that "the Internet" is a huge consumer of electricity. Below we provide ten reasons for these exaggerated claims and we offer some real data from which to build more accurate estimates.

2. Reasons for Exaggerated Forecasts

2.1   Lack of common definitions and metrics

Power in data centers is most commonly discussed in terms of power density (in W/m^2, or W/ft^2 in the U.S.). It is often unclear, however, what this watts-per-square-meter number means because the numerator and the denominator vary from use to use. A stated power density of 1000 W/m^2 could refer to the power drawn by an isolated rack, or the average power density of the building. Furthermore, extrapolating the power density of an isolated rack to the entire floor area of a building is misleading because the floor area within a building includes aisle space, office space, restrooms and hallways, all of which require much less power per square meter than computer racks.

2.2   Nameplate power versus actual power

Power needs are often determined based on the nameplate power consumption, which is the theoretical maximum amount of power that the equipment can draw. For safety reasons most

equipment never draws more than 80% of the rated power even during peak demand, and the majority of computer equipment draws much less than 80% of its nameplate rating.[2] As early as 1990, Norford et. al. [3] reported that nameplate ratings for personal computers tend to be overstated by factors of two to four. Furthermore, a more recent paper by Basler and Hofman [4] reported the electricity consumption of various other pieces of network equipment (i.e., routers, switches, multiplexers, micro repeaters, media converters) and found that the measured power was usually about 30% of the nameplate specifications. Designing for nameplate power consumption rather than actual power draws, therefore, will result in significantly oversizing building circuits and supporting systems.

2.3   Installed versus utilized circuit capacity

Power estimates are often based on maximum capacity values even when it is unlikely or impossible for the actual power to ever reach this value. For example, one data center facility fact sheet [5] explains that, "To conform to electrical code for peak power use, maximum power usage is limited to 75% of circuit values (e.g. 15 amperes (A) for a 20 ampere circuit)." In this data center, every circuit would always be oversized by at least 33%. Since many data centers are built long before the mix of internal computer equipment is determined, it is difficult to minimize the oversizing of circuits. The capacity of the installed circuits, therefore, will far exceed the actual current capacity needed.

2.4   Dual power supplies

Some computer equipment employ dual power supplies to provide sufficient backup should one circuit fail. In this case, even though the equipment draws a maximum of 6A, it would have not one but two 6A power supplies, each connected to its own circuit. Since each power supply must

be connected to a separate circuit, three 6A-rated servers with dual power supplies would require two 20A circuits—approximately twice the actual power requirements of the equipment even if it were to draw the full nameplate power.

2.5 Reduction in server dimensions

Current facility designs assume that the customer will use the latest most energy-intensive equipment which would mean that a standard rack (approximately 1.8 meters) could hold roughly 40 1U servers (where 1U= 4.445 centimeters). Since today's 1U servers can have as many processors as older 4U or 5U servers, the 1U server could consume about the same amount of electricity but with a fraction of the physical size. Most data centers, however, still use many pieces of larger, less energy intensive computer equipment.[3]

2.6 Rack and facility utilization

A typical or standard equipment rack has approximately 40U of space, all of which, in theory, could be occupied by energy-using equipment. But regardless of how many pieces of equipment can fit in a rack, many racks are under-utilized. At the data center that we studied in most detail, for example, the average rack was only one-third filled, and 47% of the audited racks had no electrical equipment at all. While revenues or payback periods are calculated based on renting only 30-40% of capacity [6], power requirements often assume 100% utilization.

2.7 Anticipation of high future loads

A recent paper by the Uptime Institute [7], using information from 15 computer manufacturers, shows the trend (from 1992 to 2010) in power use by a full rack of servers. The paper from the Uptime Institute indicates that the amount of power used by a full rack of servers is expected to

roughly double between 2000 and 2005. Given the introduction of 1U servers, and the rapid turnover of computer equipment, data centers have started designing for power-dense equipment. The recent introduction of lower powered and power managed servers, however, may mean that these anticipated loads will not materialize [8].

2.8   Oversized heating, ventilation and air conditioning (HVAC) systems

Overestimating the power needs of the computer equipment leads to an overestimate of the heat that will be dissipated from such equipment. The resulting systems will require larger chillers and fans, and more computer room air conditioners (CRAC) than needed. Corresponding electrical systems will have to be sized to accommodate a fully loaded HVAC system even though the full capacity will never be needed. Oversizing HVAC systems reduces system efficiencies and wastes energy.

2.9   Compounded safety factors

In an industry where reliability is highly valued, several systems will be oversized so that each provides redundancy. The oversizing of each system is further compounded by the fact that the engineers that design the mechanical systems are not the same engineers that design the electrical systems or the computer equipment. Each discipline adds its own safety factors. The electrical system, therefore, will be oversized for an already oversized computer and mechanical load.

2.10   Overly optimistic forecasts of the number of data centers

As a result of the slowing market, it is likely that forecasts of the number of data centers and the total floor area in these facilities are significantly overstated. Companies may not end up completing data centers or building all of the data centers that they planned. It is also possible

that some of the speculative data centers are being double counted. When new data centers are sited, owners may "shop" their power needs to more than one utility to secure favorable rates. Speculative power requests can lead to overestimates of the aggregate amount of power required for this industry.

All of the reasons above cause total data center power requirements to be portrayed as higher than actual. While the current estimates are too high, security and confidentiality concerns make it difficult to gather the data required to determine more accurate estimates of power densities or total power loads for these facilities. Companies that own data centers are often unwilling to share information about their operation because they feel it may compromise proprietary information. For example, reporting the presence of empty racks or cabinets may make the company seem unpopular or unprofitable to observers. For this reason, until this study, there were no publicly available measurements of power requirements at data centers. In this paper, we report our findings from one Silicon Valley data center and summarize billing data from four others in order to bring actual measurements and the analysis of real-world data to the debate over how much energy these facilities use. Examining the energy needs of this data center also allows us to gain a better understanding of where energy efficiency measures could be most effective.

The estimates below are based on measured data, electrical and mechanical drawings, equipment counts, manufacturer's specifications for the equipment at this data center, electricity billing data, and, where specified, previous relevant studies. While still rough, these estimates provide a benchmark for a variety of electricity uses within data centers and offer a sense of the complexities involved with estimating the power needs of these facilities.

3. Measurements from a Silicon Valley Data Center

3.1 General description of the facility

The data below were collected from a 11,645 m^2 facility located in Silicon Valley, California (USA). Like many data centers throughout the country, this facility was built within an existing building shell to minimize construction time. At the time these measurements were taken, there were 2,555 m^2 of active computer rooms that occupied 22% of the total building floor area. (See Figure 1.) The facility also contained office space, equipment rooms, and areas still under construction. All space under construction is included in the "Other Area" category in Figure 1. Bathrooms, hallways, and lobbies are also included in "Other Area." In addition to the renovated space, there was approximately 1,170 m^2 of floor area that remained in its prior use. All equipment in this area, therefore, was in this facility prior to the recent renovation. Thus, the power loads from this part of the building do not represent new power requirements due to growth of the Internet, or the addition of a data center. This "Prior-Use Area" is approximately 10% of the total facility's floor space.

All of the space in the active computer rooms was leased; however, on average, only one-third of the rack capacity was used. This space contained both cages that could hold from five to several dozen racks and free standing cabinets (racks with doors). The equipment in an easily accessible portion of one computer room was inventoried to determine the different types of computer equipment currently in this data center. The area was part of a co-location facility where the computer equipment was enclosed in cabinets. These cabinets were located in an area that covered approximately 240 m^2. This area was selected because the equipment could be easily

viewed and counted. Racks within cages were not selected because access to the cages was restricted and it was impossible to accurately inventory the computer equipment from outside the cages. The data, therefore, may over-represent smaller customers because they tend to rent cabinets rather than larger cages. The inventory for this area is reported in Table 1.

Approximately 47% of the racks in this space were empty. (A few had cable connections but no energy-using equipment.) The remaining racks had varying amounts of equipment. Servers, ranging in size from 1U to 8U accounted for 61% of the utilitized rack space. One third of these servers were 2U servers. While the data in Table 1 give a sense of the types of equipment in this space, it is difficult to estimate power consumption based on this information because the energy demands vary depending on the internal configuration of the equipment. Although servers generally use less power per unit area than routers, one 4U server may require significantly more power than another 4U server depending on its vintage, design, function, etc. As a result, it is difficult to determine the power requirements from the external appearance of the computer equipment.

3.2 *Determining power demands from computer equipment*

All of the computer equipment was connected to power distribution units (PDUs) that displayed the voltage and current for each of the three phases. Power readings from these PDUs were taken in January 2001. The apparent power requirement for the computer equipment was approximately 445 kW. A power factor of 0.97 was used to convert from apparent to real power. Newer computer equipment usually corrects the incoming power to eliminate harmonic distortions that might cause disruptions. For example, new switching power supplies for Sun computers have active power factor correction to at least 0.99 in most cases.[4] Measurements

from a both a New York City data center and an Oakland data center, however, indicated that the aggregate power factor for computer equipment (including routers, switches and hubs) is closer to 0.97. The real power requirement for the computer equipment was approximately 432 kW, resulting in a computer power density slightly less than 170 W/m^2.

3.3 Power used in the prior-use area

An approximate average power density for the "Prior-Use" area, which represented 10% of the total building area, was determined from historic billing data. The power density was approximately 215 W/m^2 over this 1,170 m^2 area. This value includes all of the equipment, lights, fans and plug loads in this area but does not include the power needed to provide chilled water to the air conditioning units (i.e., the central plant requirements—see 3.8 below) because the HVAC central plant power was on a separate meter.

3.4 Power used by computer equipment in office space

The number of computers was much less than would be expected in an equally large commercial office space since the main employees of the building were mechanical and electrical personnel. The average heat gain for a typical office computer is approximately 55 watts [9]. A medium sized monitor would add an additional 90 watts [10]. This estimate is for an active computer and does not take into account that the computer and monitor would draw less if it is in a power saving mode, nor the fact that these computers are probably not on 24 hours a day. Furthermore, a laptop would require less power and generate less heat than a desktop computer. We assumed that the twelve computers found in the office space consumed 145 watts at all times. This is approximately 1,740 watts, or 1.1 W/m^2 over the 1,330 m^2 office space.

3.5 Lighting

The electrical drawings indicated that the power density of the lighting in the computer rooms was approximately 12 W/m^2. Mechanical and equipment rooms tend to have a slightly lower lighting power density; therefore, a value of 8 W/m^2—a typical value for this type of room determined from an earlier study on lighting [11]—was used for these areas. In the office space of a typical commercial building, lighting requires approximately 19 W/m^2 [11]. Using these values, the total load from lighting was approximately 117 kW. (This does not include lighting in the Prior-Use area.)

3.6 Other Loads

In addition to lights and computers, other office equipment such as copiers and fax machines contribute small power loads throughout the office space. A recent *ASHRAE Journal* reported the heat gain to be approximately 1,100 watts from an office copier, 30 watts from a facsimile machine, 25 watts from an image scanner, and 550 watts from a large office laser printer [9]. These numbers do not take into account power saving modes or end-of-the-work-day shutdowns but they give a reference point for calculating the additional loads in this space. For our calculations, we assumed that this additional equipment drew just 3 W/m^2 since the power density of the computers in this area was already included in an earlier step, and since this space was not densely occupied. In addition, 1 W/m^2 was added to all "other" areas to account for small miscellaneous loads. These values carry with them less certainty than the measured data reported above, but they are small in comparison to the larger loads of the computers and HVAC system (discussed below).

3.7 Losses due to auxiliary equipment

As electricity passes through the uninterruptible power supplies (UPSs) and power distribution units (PDUs) some is lost to the internal components in this equipment. With a full load, UPSs are approximately 95% efficient, and PDUs can be close to 98% efficient. As the load drops, however, these efficiencies decrease. Since these systems were under light loads, we assumed that the PDU and UPS efficiencies were on the lower end of these ranges and that the losses were approximately 5% and 7%, respectively. As a result, approximately 22 kW were consumed by the PDUs and 32 kW were used by the UPSs, for a total of 54 kW. In addition, line losses and other auxiliary equipment such as building controls, fire alarms, security systems, telephone systems, and backup diesel generators also use small amounts of power. Overall, approximately 100 kW were consumed by auxiliary equipment and line losses. While these power draws occurred throughout the facility, they were allocated to the active computer rooms since the majority of this auxiliary equipment was in the building for the sole purpose of supporting the computer rooms.

3.8   Power for the HVAC central plant

The active chiller in this facility was an 800 ton York chiller. (An additional 800 ton chiller was also onsite as a backup.) The total heat load in this facility, as indicated by the monitor on the chiller, was approximately 320 tons. Since the chiller required approximately 0.52 kW/ton, demand from the chiller was approximately 166 kW. The active cooling tower had a 30 horsepower, or approximately 22 kW, motor. However, since the cooling tower was running at only 40% of capacity, the motor was using the minimum amount of power: 2.2 kW or 10% of the design.[5] While the chiller and the cooling tower were operating at 40% of capacity, the pump to circulate the chilled water through the facility required a constant horsepower regardless of the

load. This pump, therefore, required full power or approximately 45 kW.[6] In total, the central plant (including the chiller, cooling towers and pump) required approximately 213 kW.

3.9 Power for air distribution

The computer rooms in this facility employed twelve 50-ton CRAC units and six 30-ton CRAC units. In addition, there were four additional air conditioning units that cooled air remotely and then blew the cool air into the computer rooms. Overall, therefore, there were 22 units; for redundancy purposes, however, only 18 ran at one time. Under the current light loads, these units were operating at approximately 30% of capacity. The fans within these units, however, ran constantly. The fans in a typical 50-ton CRAC unit require approximately 10 horsepower or 7.5 kW each. The fans in the smaller 30-ton units used slightly less power. A CRAC with dehumidifiers and reheat systems as well as internal monitors and other components, however, requires closer to 40 HP or approximately 30 kW. Assuming that 5 of the CRAC units were able to dehumidify and reheat and that the others were just cooling units, the 22 units would use a total of approximately 215 kW. In addition, the office space had its own packaged air-handling unit and additional fans were located throughout the building. As a result, the total air distribution system for this facility was estimated to be 250 kW.

3.10 Total power needs

The computer rooms in this facility were designed so that the computer equipment could draw an average of 646 W/m^2. As shown in Table 2, however, the actual *computer power density* was 169 W/m^2—just over one-fourth of the design value. C*omputer power density*, however, includes only the power drawn by the computer equipment and does not include power required by the supporting systems. It is not, therefore, indicative of the total power needs of this data center.

Over the building's 11,645 m^2 floor area, the average *building power density* was 118 W/m^2. (All power density assumptions are listed in Table 3.) The building's total power requirement, approximately 1.4 MW, was determined by multiplying the power density for each area by the appropriate floor area. (See Table 4 for total power needs by end use.) This monthly average was confirmed by the electricity billing data from the local utility.

Average *building power densities*, however, are also not indicative of the power required by data centers because many computer rooms have been added to buildings with previously existing energy needs. In these cases, a significant portion of the power required is not new power or power required by the data center. Furthermore, because the ratio of computer room to other space varies between facilities, it is also impossible to *compare* these power densities. The average *building power density* of a skyscraper with one large densely packed computer room, for example, would most likely be much less than the average *building power density* of a small sparsely filled computer room in a small facility despite the fact that the data center in the skyscraper requires much more energy.

Estimates of *total computer room power density* are most indicative of data center power needs. (See Table 2.) We define the *total computer room power density* as the power drawn by the computer equipment and all of the supporting equipment such as PDUs, UPSs, HVAC and lights (in watts) divided by the computer room floor area (in square meters). After including all of the support systems, we estimated that the *total computer room power density* for this building was approximately 355 W/m^2 (33 W/ft^2). This value was supported by a review of billing data for

four additional data centers throughout the country. In each of these four facilities, we found that the *total computer room power density* was less than 430 W/m^2 (40 W/ft^2).[7]

Nearly one half of the power used to support the computer rooms went to the computer equipment. (See Figure 2.) The remaining power was used for the HVAC and auxiliary equipment as well as other end uses such as lighting. The HVAC system (including the central plant and the air distribution, or fans) accounted for approximately 38% percent of the power. Lighting represented only a small percentage—less than 3% of the power needs.

4. Conclusions

Standardized definitions and estimation methodologies can facilitate comparisons of data center energy use. In particular, estimates of *total computer room power density* allow for comparisons of data center power use between buildings of different sizes as well as between data centers at different stages of development. The *total computer room power density* captures all power drawn by the computer equipment as well as by the supporting equipment such as HVAC, PDUs and UPSs (in watts) divided by the computer room floor area (in square meters). In the data center examined in this study, *total computer room power density* was determined to be approximately 355 W/m^2 (33 W/ft^2), which is much less than the numbers often cited by the media.

To support the 2,555 m^2 of critical computer room floor area in this facility, the data center drew approximately 900 kW of power. This 900 kW is most indicative of the new power requirements at this data center due to Internet growth. The remaining power (approximately 500 kW)

required by this facility was used for "Prior Uses" and is not indicative of additional power requirements due to Internet growth. When determining power requirements of data centers, care should be taken not to include previously existing loads.
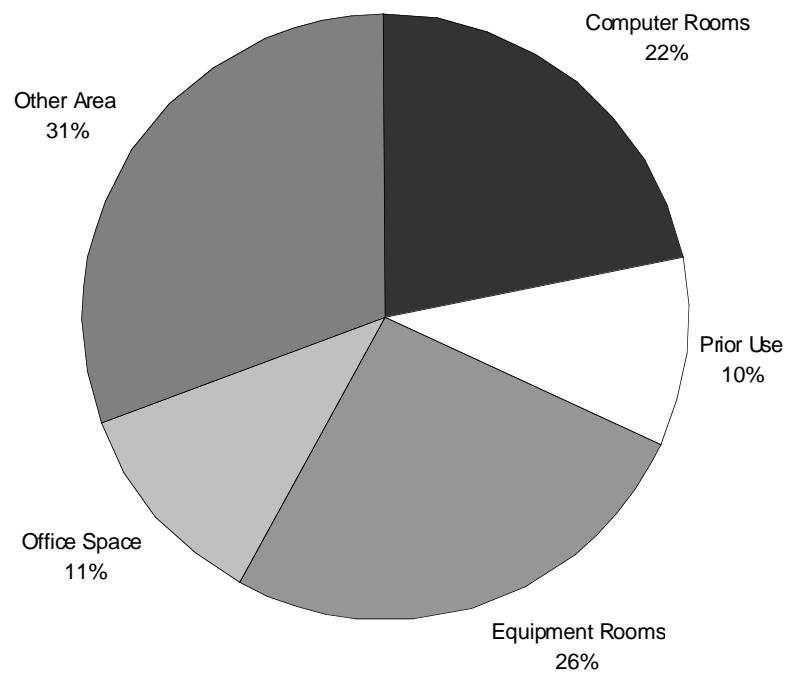
While not as high as reported, data center power densities are much higher than those for typical commercial office buildings because of the densely packed computer equipment. Since many systems within data centers are designed inefficiently, energy efficiency measures can lead to significant energy savings. Targeting computer equipment for energy efficiency gains is an effective measure since computer equipment accounts for nearly one-half of electricity consumption in data centers. Reducing the energy requirements of the computer equipment and getting more accurate estimates of the computer equipment's electricity use can also have a significant impact because most of the other systems within the facility are sized to the estimated power needs of this equipment.

While this study serves as a benchmark for power densities found at data centers, additional studies and collaborative efforts between utilities, data centers, and local governments are needed. Further studies can help to create a better understanding of the real power needs of data centers and also help to determine appropriate energy efficiency measures for these facilities.

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Computer Rooms
22%

Prior Use
10%

Equipment Rooms
26%

Office Space
11%

Other Area
31%

fans, CRAC units, AHUs
24%

computer equipment
48%

central chiller plant
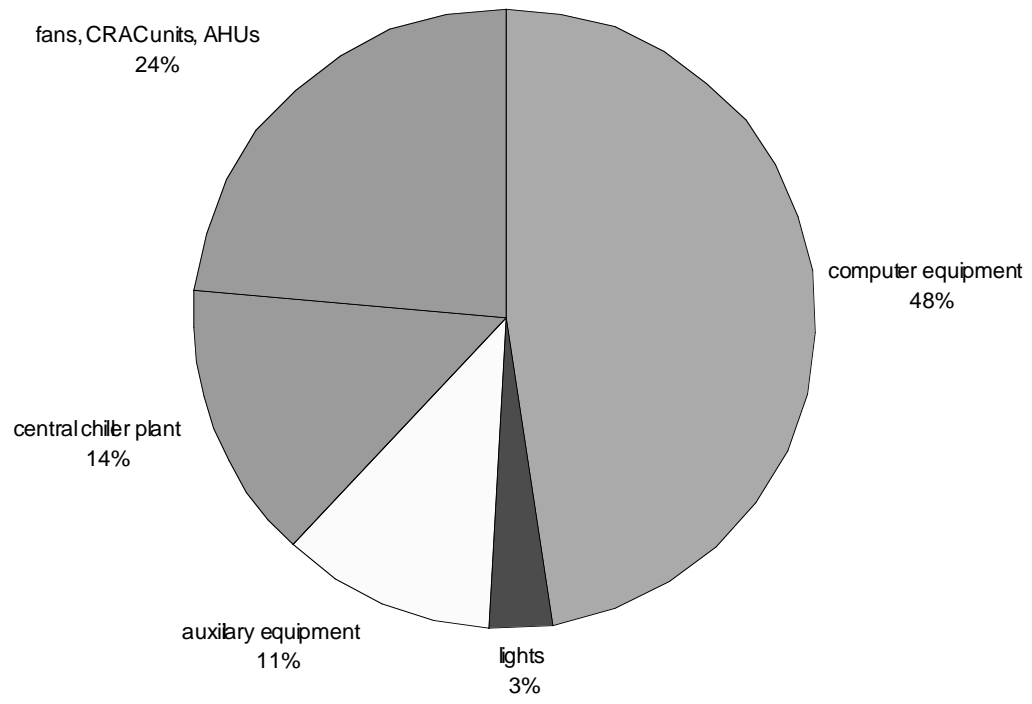14%

auxilary equipment
11%

lights
3%

Figure captions

Fig. 1. Facility floor space (11,645 m^2 total).

Fig. 2. Total computer room power by end use.

Type of Equipment	Number	Space in 'U's (where 1U=4.445 cm)	Percent of utilized rack space devoted to equipment
Servers	229	596	61%
Switches	101	177	18%
Disks	18	88	9%
Routers	13	81	8%
Firewalls	8	15	2%
Other	12	19	2%
Total	**381**	**976**	**100%**

Table 1. Inventory of equipment found in cabinets in a co-location hosting facility. The above equipment was located in approximately 240 m^2 of a computer room in Silicon Valley, California. Data collected by Bruce Nordman and Jennifer Mitchell-Jackson, November 2000.

Term	Definition	Results
Computer Power Density	Power drawn by the computer equipment (in watts) divided by the computer room floor area (in square meters or square feet)	169 W/m^{2a} 16 W/ft^2
Building Power Density	Total power drawn by the building (in watts) divided by the total floor area of the building (in square meters or square feet)	118 W/m^2 11 W/ft^2
Total Computer Room Power Density	Power drawn by the computer equipment and all of the supporting equipment such as PDUs, UPSs, HVAC and lights (in watts) divided by the computer room floor area (in square meters or square feet)	355 W/m^2 33 W/ft^2

[a] A conversion factor of 10.76 ft^2/m^2 (0.0929 m^2/ft^2) was used to convert from English to metric units.

Table 2. Data center key terms and findings. Results are from a 11,645 m^2 facility in Silicon Valley, California.

Area Breakdown	Floor Area (m^2) [a]	Direct Use Power Densities (W/m^2)			Supporting Equipment Power Densities (W/m^2)			Power Density (W/m^2) [c]
		computers or prior use	lights	other	auxiliary equipment	central chiller plant [c]	fans, CRAC units, AHUs [c]	
Computer Rooms	2,555	169	12	0	39	51	83	355
Prior Use	1,170	215 [b]	n.a.	n.a.	n.a.	50	n.a	265
Equipment Rooms	2,990	0	8	0	0	2	3	13
Office Space	1,330	1	19	3	0	6	9	38
Other Floor Area	3,600	0	11	1	0	3	4	19
Total Building	11,645	59	10	1	9	18	21	118

[a] A conversion factor of 10.76 ft^2/m^2 (0.0929 m^2/ft^2) was used to convert from English to metric units.

[b] Lights, other, auxiliary equipment and fans for the "Prior Use" area are included in the 215 W/m^2. Billing data for this area did not permit a more detailed breakdown.

[c] Note that some values differ slightly from earlier write-up of results [12] because of recent modifications to the calculation methods.

Table 3. Power density by end use from a data center facility in Silicon Valley, California.

Area Breakdown	Direct Use Power (kW)			Supporting Equipment Power (kW)			Total Power (kW) [a]
	computer equipment or prior use	lights	other	auxiliary equipment	central chiller plant [a]	fans, CRAC units, AHUs [a]	
Computer Rooms	432	30	0	100	131	213	907
Prior Use	252	n.a.	n.a.	n.a.	59	n.a.	311
Equipment Rooms	0	23	0	0	5	9	36
Office Space	2	26	4	0	7	12	51
Other Floor Area	0	39	4	0	10	16	69
Total	686	117	8	100	213	250	1,374

[a] Note that some values differ slightly from earlier write-up of results [12] because of recent modifications to the calculation methods.

Table 4. Total power demanded by end use as found in a 11,645 m^2 facility in Silicon Valley, California.

Endnotes

[1] A conversion factor of 10.76 ft^2/m^2 (0.0929 m^2/ft^2) was used to convert from English to metric units.

[2] See Mitchell-Jackson, Jennifer, "Energy Needs in an Internet Economy: A Closer Look at Data Centers," May 2001 for details on where these exaggerations occur, and further information other parts of this paper. Document available at http://enduse.lbl.gov/Projects/InfoTech.html.

[3] It should also be noted that new bladed servers offer even higher server densities than 1 U servers. Information on the RLX System 324, for example, states that one rack can support 336 servers. Manufacturer reports, however, indicate that these servers require less power per square meter than 1 U servers. See RLX Technologies' White Paper on Redefining Server Economics, May 2001 for more details on bladed servers. Document available at http://www.rlxtechnologies.com/media/kits/.

[4] Email from Sun Microsystems technical support desk, 07 February 2001. Email text as follows: an active power factor correction to at least 0.99 "has become a regulatory requirement for almost all new switching power supplies, with particularly strict regulations in the European Union. Uncorrected power factor can cause core saturation in the distribution transformers leading to early failure and decreased efficiency in the distribution grid." Also supported by The Uptime Institute, 2000.

[5] Data gathered from the manufacturer.

[6] From manufacturer's specification.

[7] The four values were: 85 W/m^2, 365 W/m^2, 375 W/m^2, and 410 W/m^2.